Supernovae as sources of interstellar dust

星間ダストの供給源としての超新星

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1-1. Introduction

Supernovae are important sources of dust?

・Evolution of dust throughout the cosmic age

– A large amount of dust (> 10^8 M_{sun}) in z > 5 quasars

– Inventory of interstellar dust in our Galaxy

・Possible formation sites of dust

– metal-rich ejecta of supernovae (Type II/Ib/Ic and Ia)

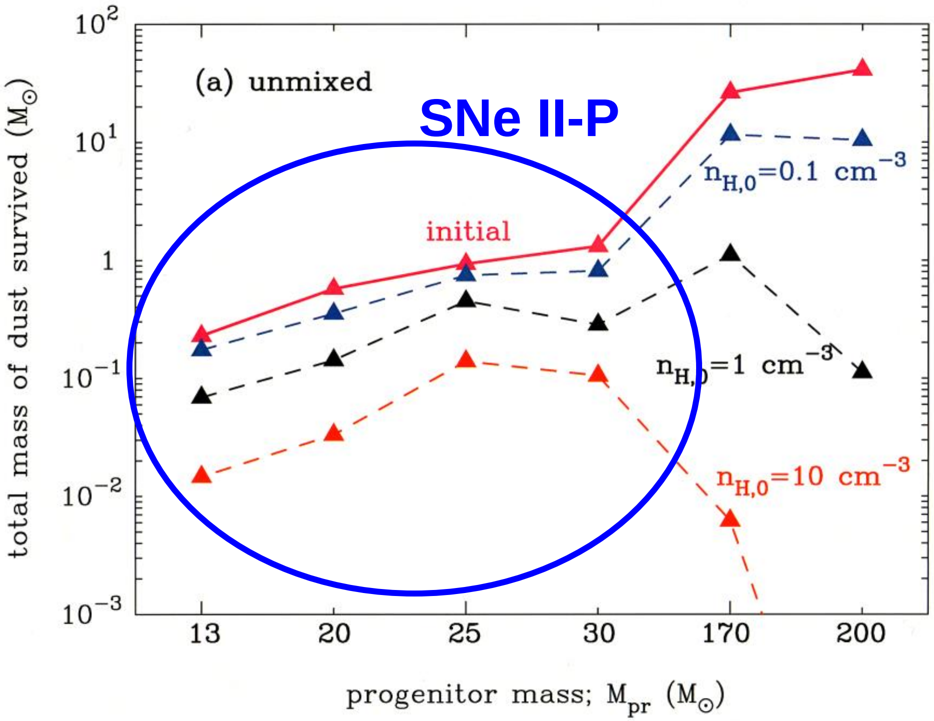
– mass-loss winds of AGB stars

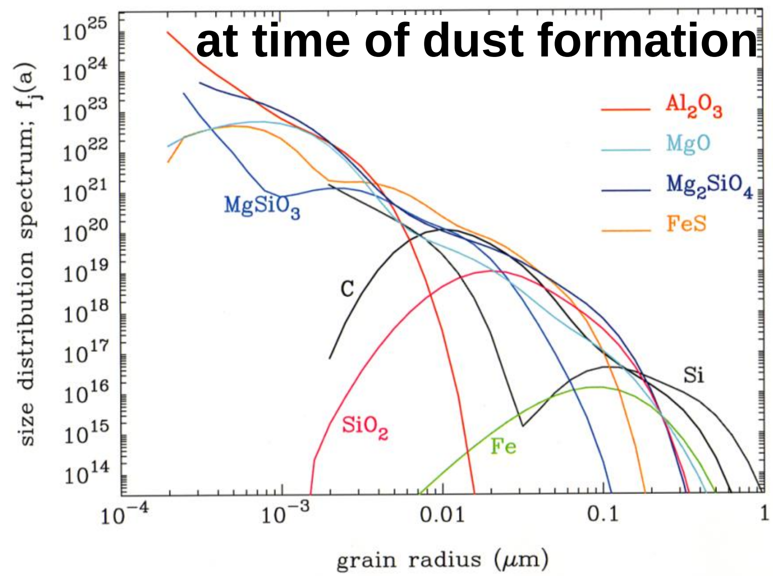
– grain growth in the ISM (molecular clouds)

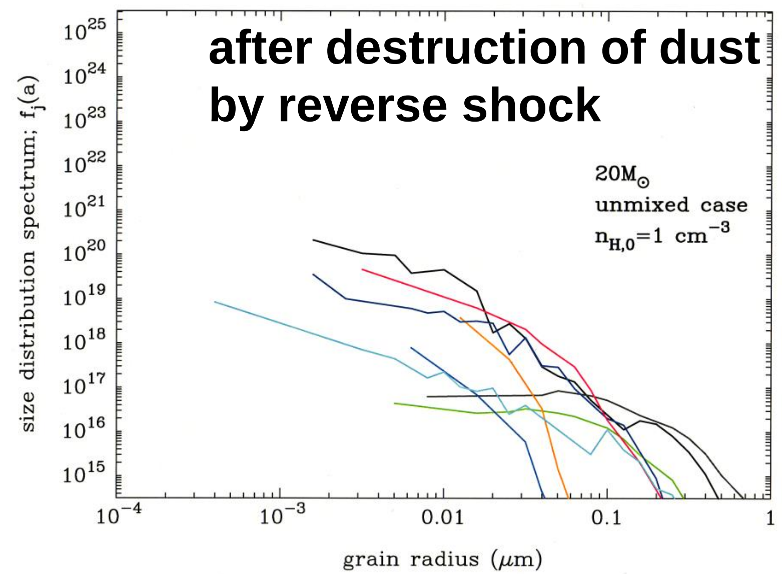
– mass-loss winds of massive (RG and WR) stars, novae, quasar outflow …

1-2. Mass and size of dust ejected from SN II-P

Nozawa+07, ApJ, 666, 955



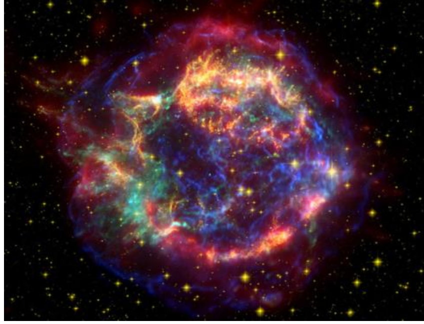




total dust mass surviving the destruction in Type II-P SNRs; 0.07-0.8 Msun ($n_{H,0}$ = 0.1-1 cm^{-3})

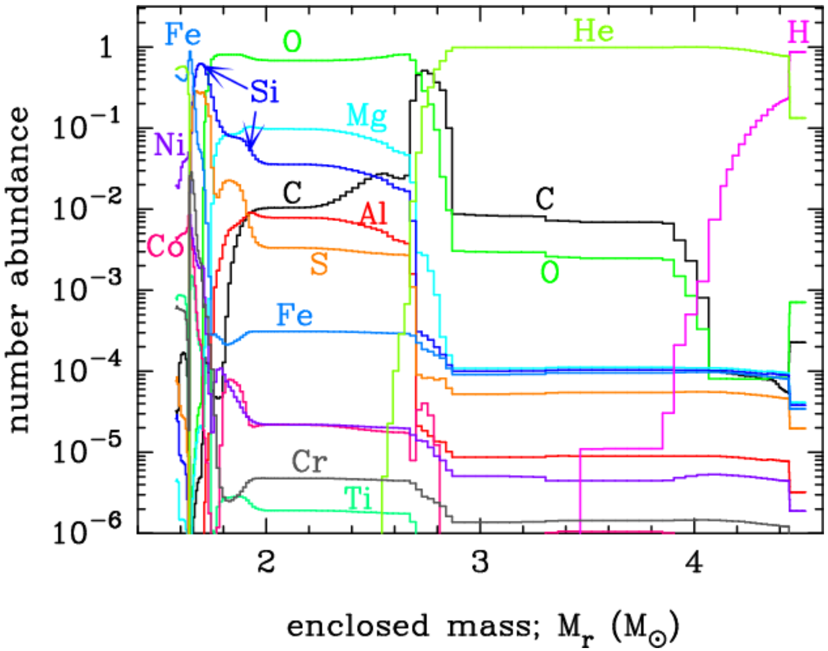
size distribution of surviving dust is domimated by large grains (> 0.01 μm)

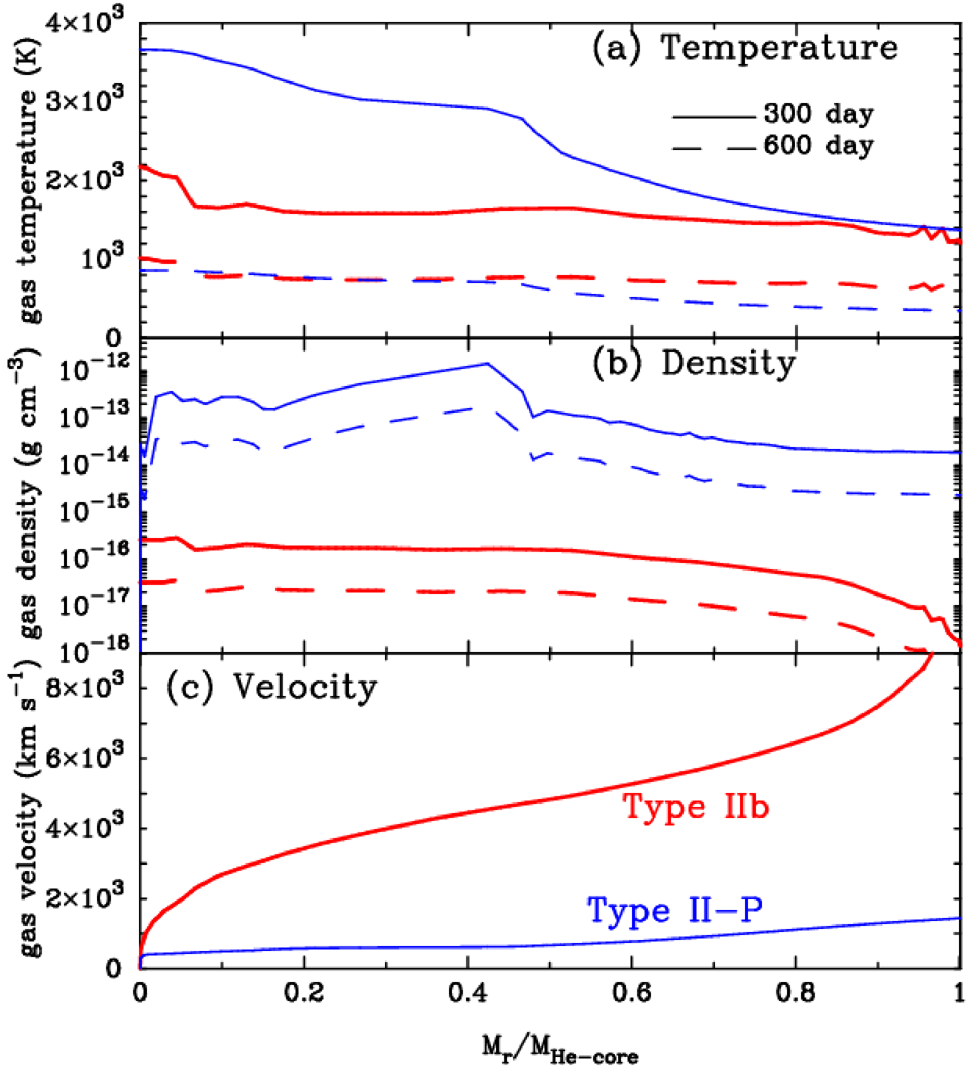
2-1. Dust formation in Type IIb SN



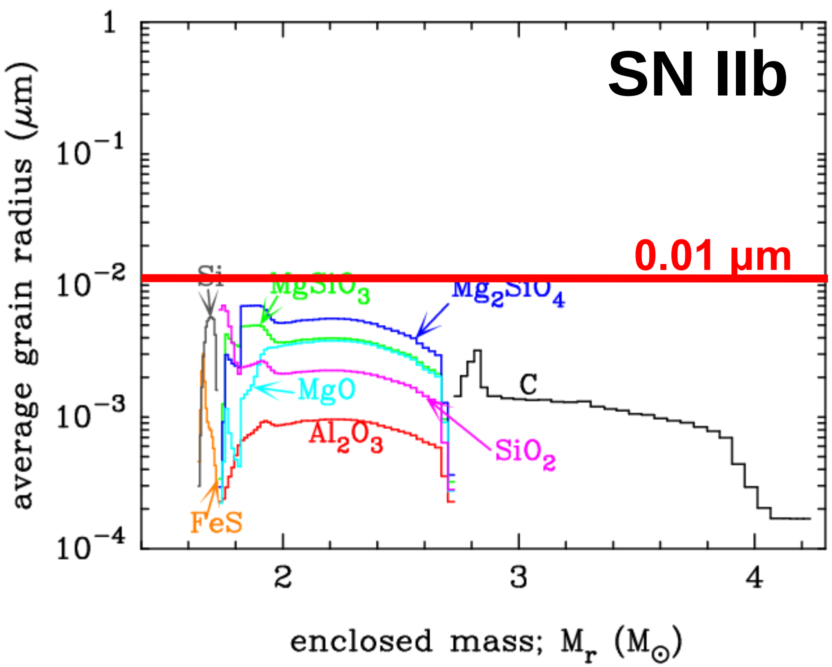
○ SN IIb model (SN1993J-like model)

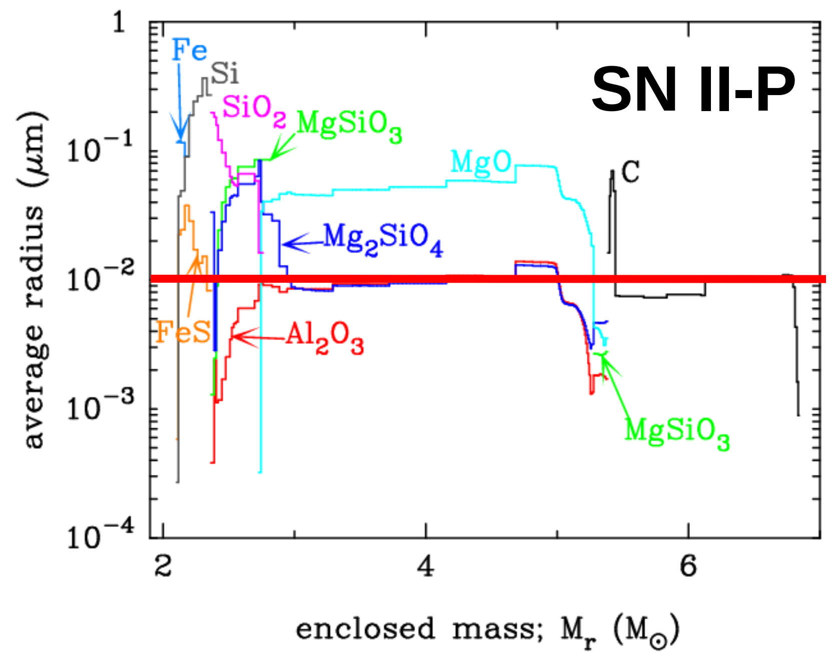
- M_{eje} = 2.94 Msun
  M_{ZAMS} = 18 Msun
  $M_{H\text{-}env}$ = 0.08 Msun
- E_{51} = 1
- $M(^{56}Ni)$ = 0.07 Msun





2-2. Dependence of dust radii on SN type





— condensation time of dust
300-700 d after explosion

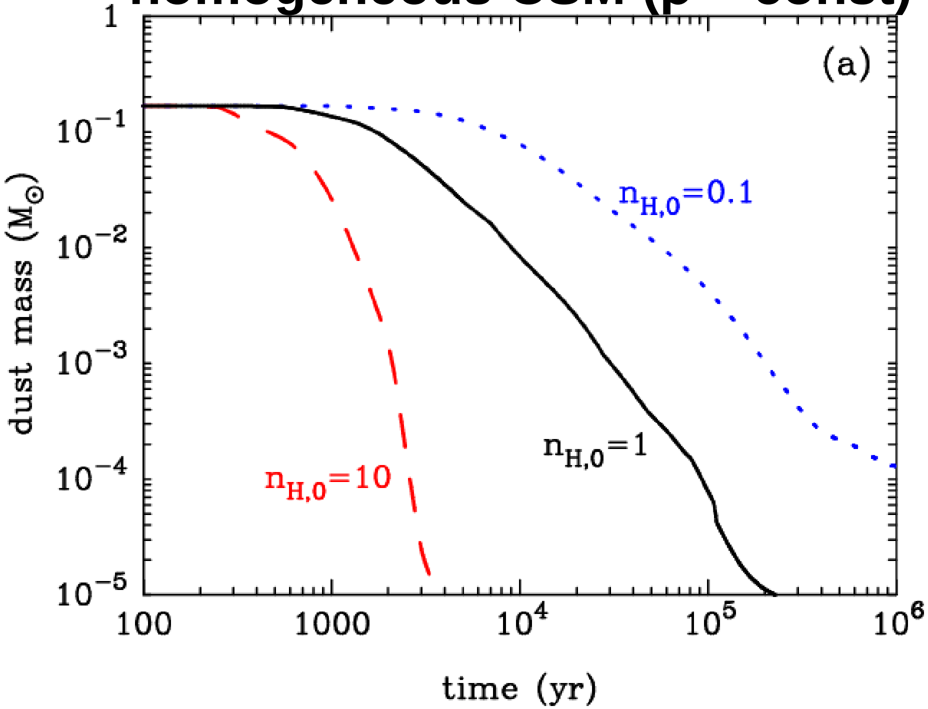
— total mass of dust formed
- **0.167 Msun in SN IIb**
- **0.1-1 Msun in SN II-P**

Nozawa+10, ApJ, 713, 356

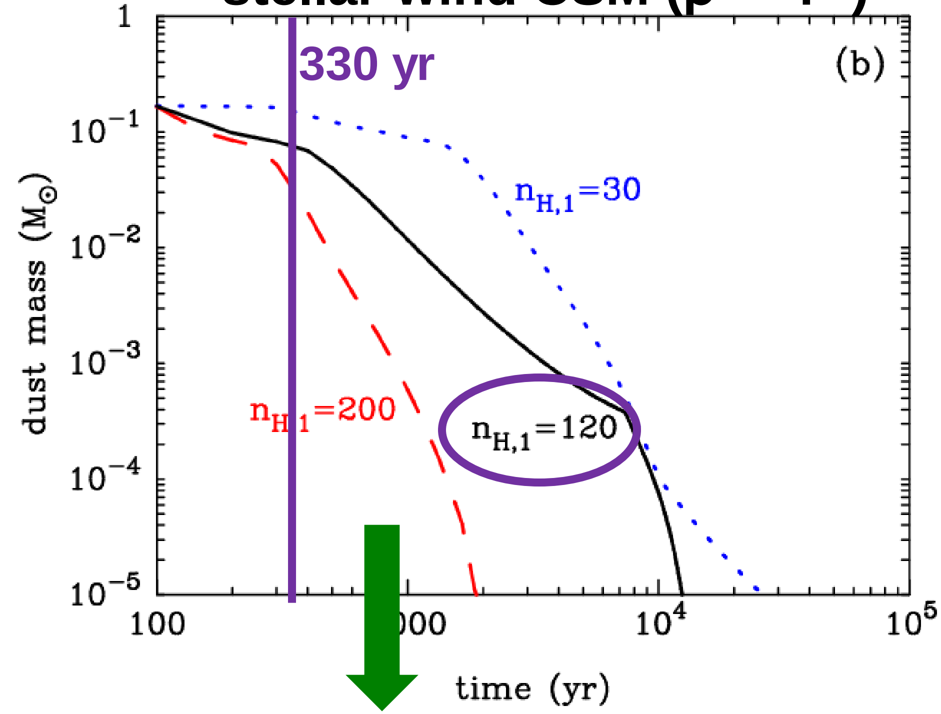
— the radius of dust formed in H-stripped SNe is small
- **SN IIb without massive H-env → a_{dust} < 0.01 μm**
- **SN II-P with massive H-env → a_{dust} > 0.01 μm**

2-3. Destruction of dust in Type IIb SNR

homogeneous CSM (ρ = const)



stellar-wind CSM ($\rho \propto r^{-2}$)



$n_{H,1}$ = 30, 120, 200 /cc ➔ dM/dt = 2.0, 8.0, 13x10^{-5} M_{sun}/yr for v_W=10 km/s

Almost all newly formed grains are destroyed in shocked gas within the SNR for CSM gas density of n_H > 0.1 /cc

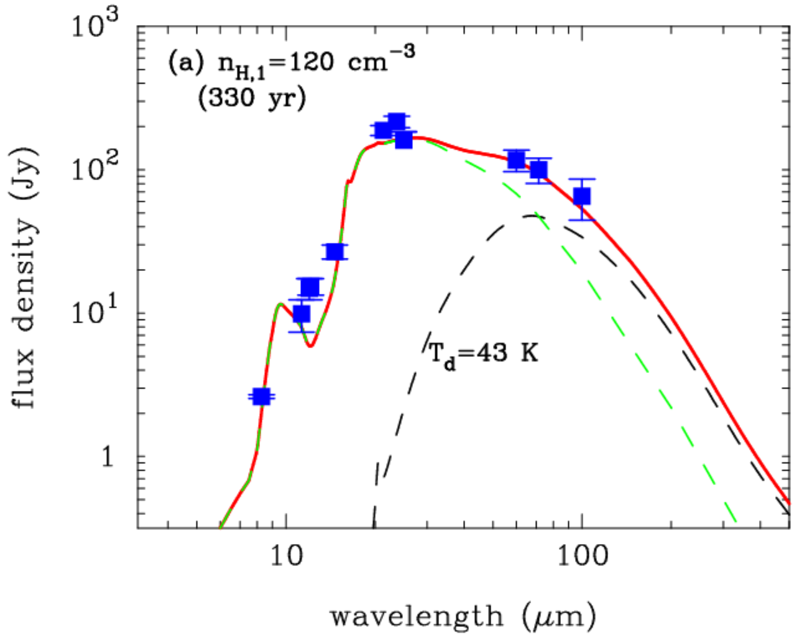
➔ **small radius of newly formed dust**

➔ **early arrival of reverse shock at dust-forming region**

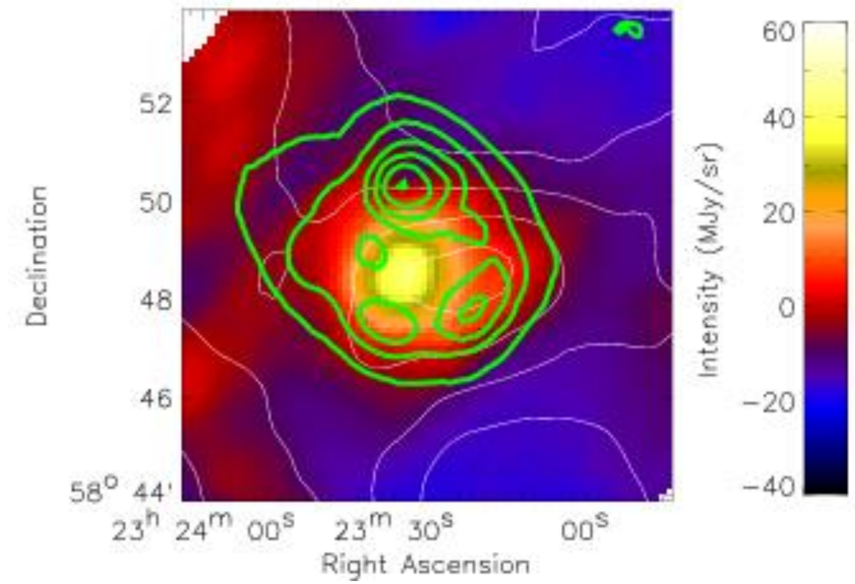
Nozawa+10, ApJ, 713, 356

2-4. IR emission from dust in Cassiopeia A SNR

Nozawa+10, ApJ, 713, 356



AKARI corrected 90 μm image



- **total mass of dust formed**
  M_{dust} = 0.167 M_{sun}
- **shocked dust : 0.095 M_{sun}**
  $M_{d,warm}$ = 0.008 M_{sun}
- **unshocked dust :**
  $M_{d,cool}$ = 0.072 M_{sun}
  with T_{dust} ~ 40 K

AKARI observation

$M_{d,cool}$ = 0.03-0.06 M_{sun}
T_{dust} = 33-41 K
(Sibthorpe+10)

Herschel observation

$M_{d,cool}$ = 0.075 M_{sun}
T_{dust} ~ 35 K (Barlow+10)

3-1. Difference in estimate of dust mass in SNe

・ Theoretical studies

— at time of dust formation : M_{dust}=0.1-1 M_{sun} in CCSNe
(Nozawa+03; Todini & Ferrara 01; herchneff & Dwek 10)

— after destruction of dust by revers shock (SNe II-P) :
M_{surv}~0.01-0.8 M_{sun} (Nozawa+07; anchi & Schneider 07)

dust amount needed to explain massive dust at high-z

・ Observational works

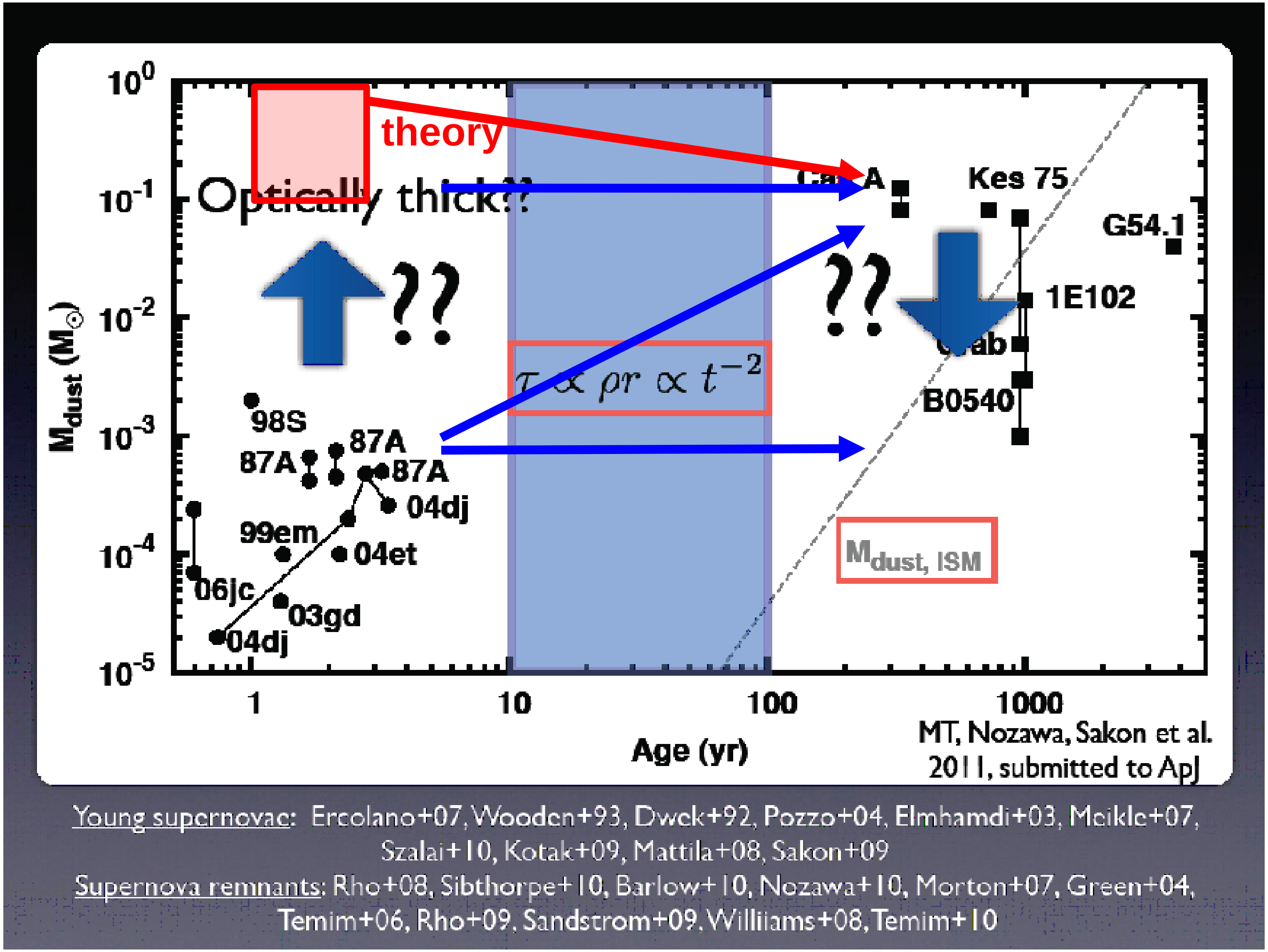
— MIR observations of SNe : $M_{dust} < 10^{-3}$ M_{sun}
(e.g., Ercolano+07; Sakon+09; Kotak+09)

— submm observations of SNRs : $M_{dust} > 1$ M_{sun}
(Dunne+03; Morgan+03; Dunne+09; Krause+05)

— MIR/FIR observation of Cas A : M_{dust}=0.02-0.075 M_{sun}
(Rho+08; Sibthorpe+09; Barlow+10)

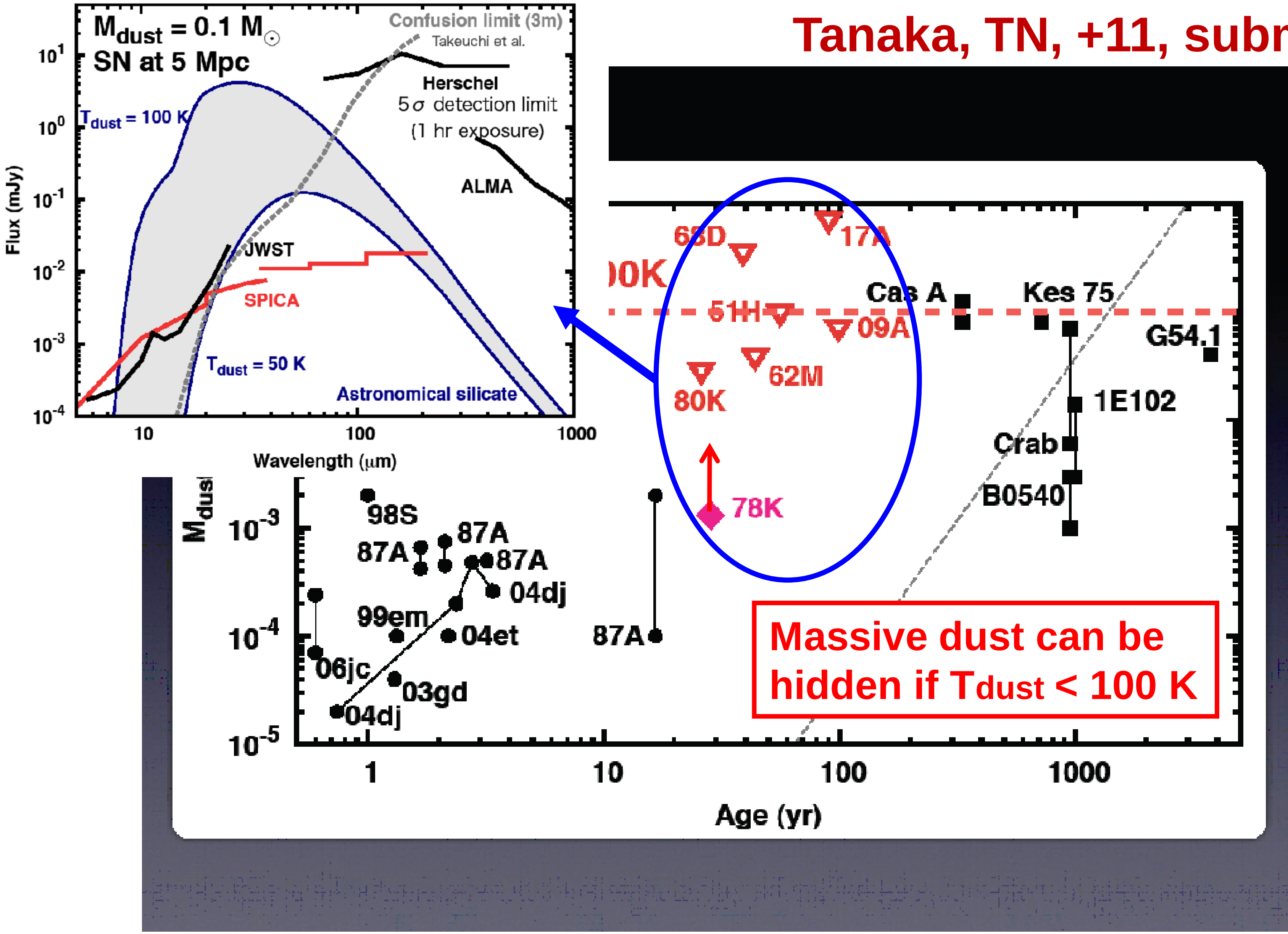
3-2. Missing-dust problem in CCSNe

Tanaka, TN, +11, submitted



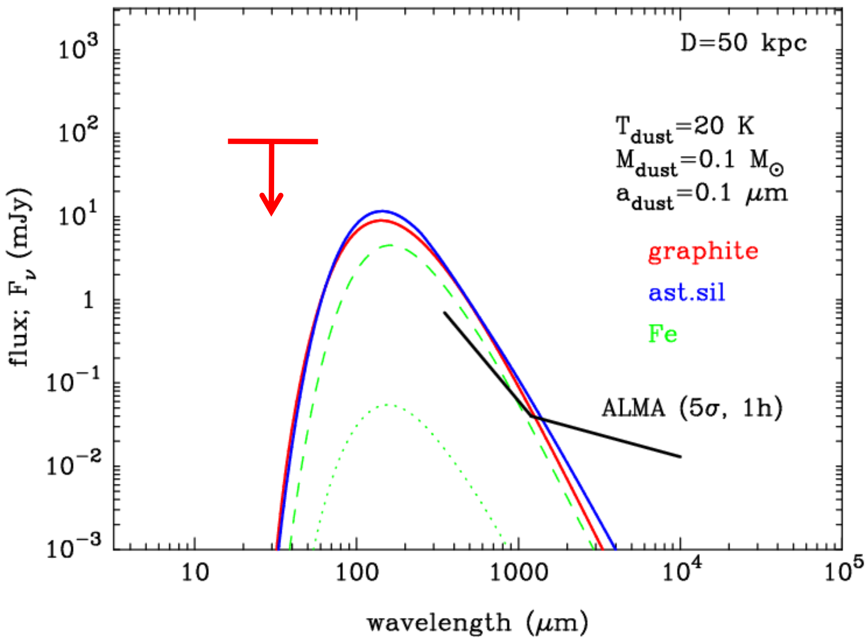
3-3. Detectability of SNe-dust with SPICA

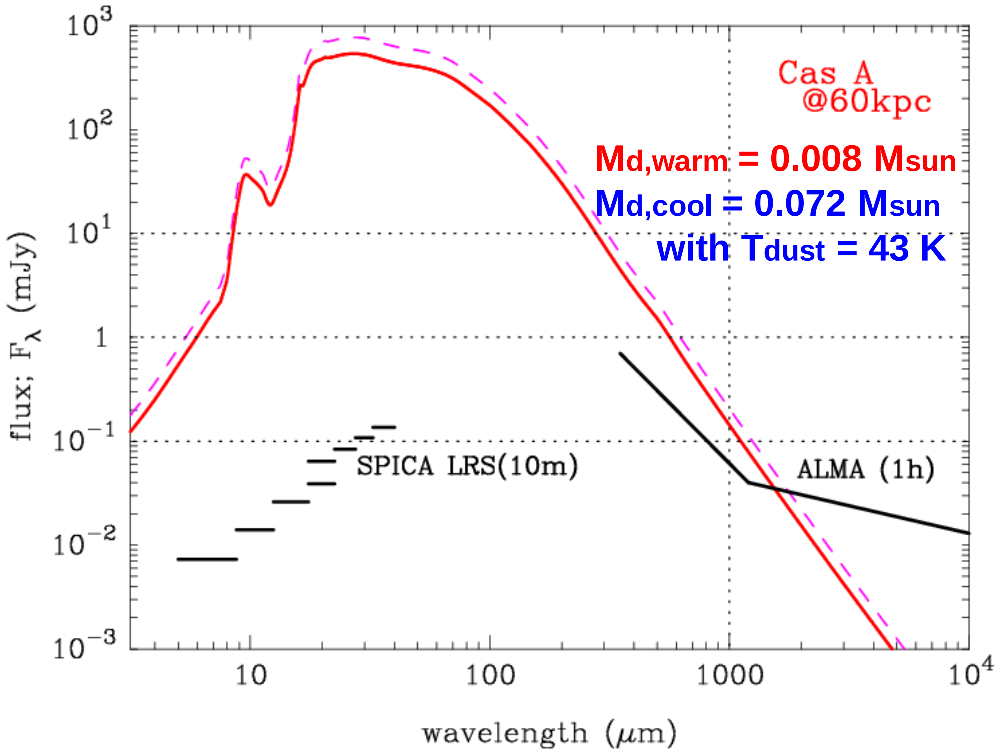
Tanaka, TN, +11, submitted



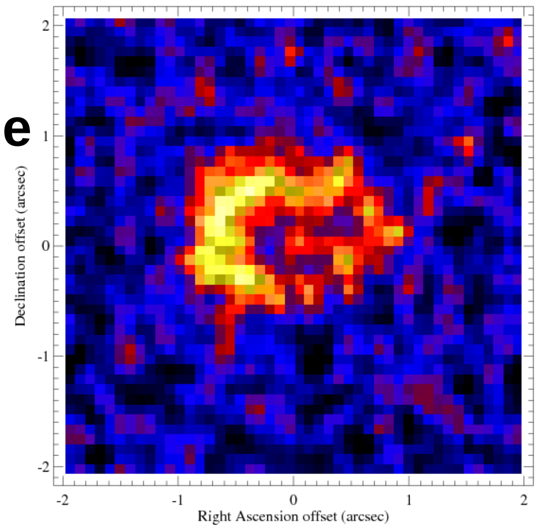
Massive dust can be hidden if Tdust < 100 K

3-4. Detectability of cold dust with ALMA





SN1987A MIR image

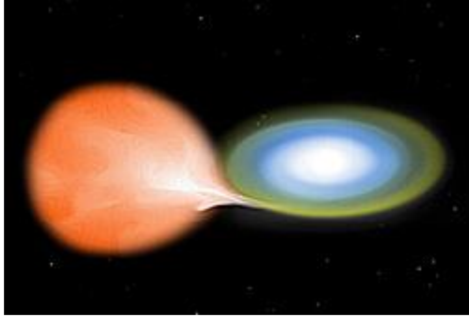


(Gemini T-ReCS, Bouchet+04)

— **SN 1987A in LMC**
diameter : 2", most feasible

— **1E0102.2-7219 in SMC**
diameter : 40"
too extended to be detected
➔ integration time : ~100 day

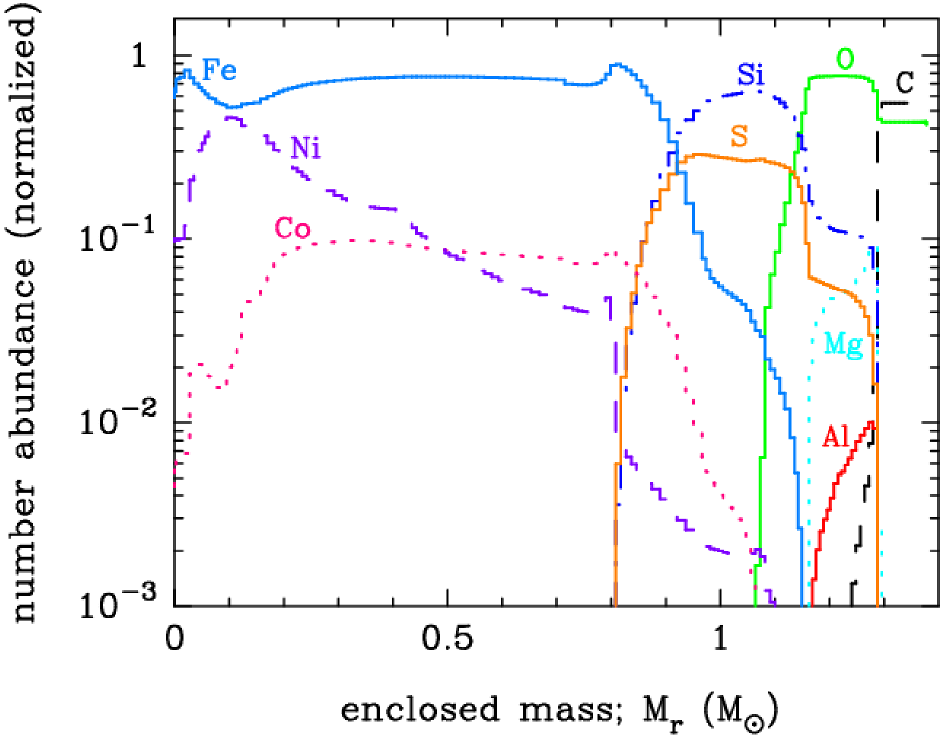
4-1. Dust formation in Type Ia SN

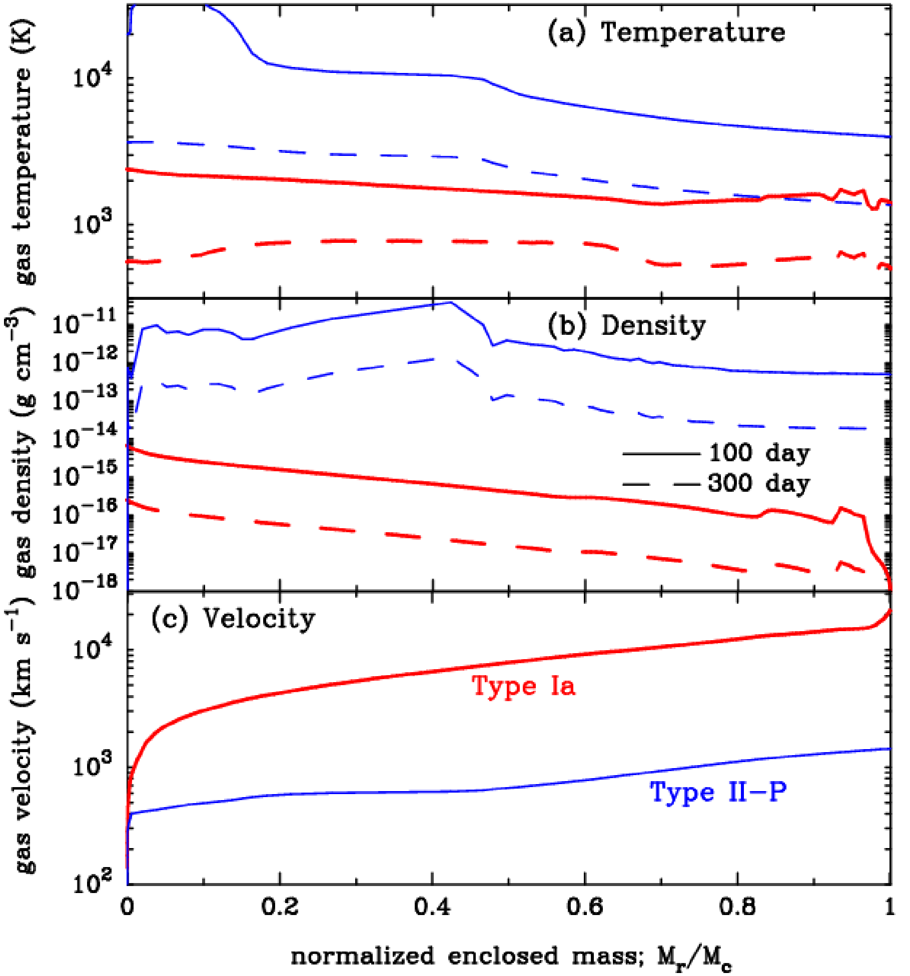


○ Type Ia SN model

W7 model (C-deflagration) (Nomoto+84; Thielemann+86)

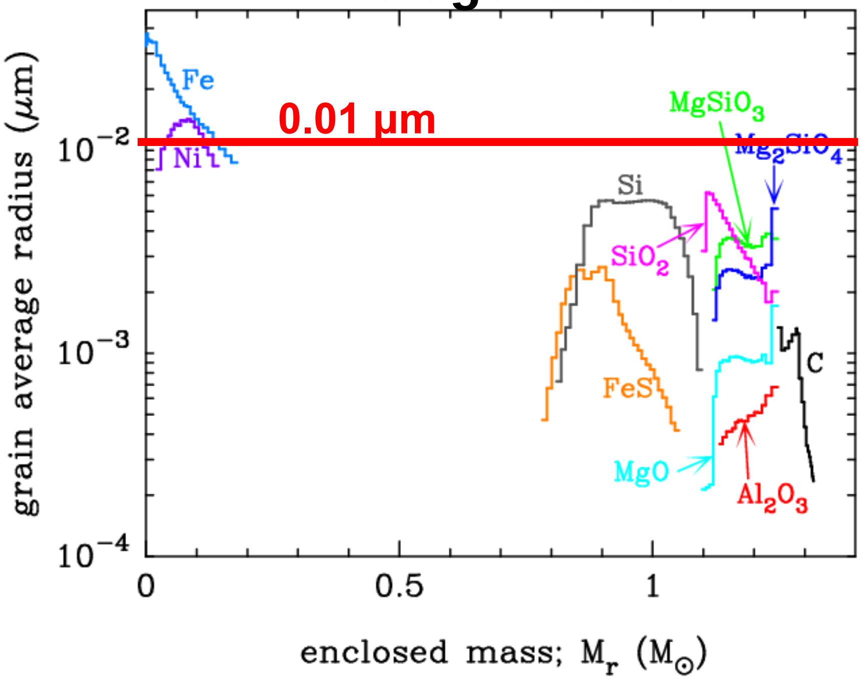
- M_{eje} = 1.38 Msun
- E_{51} = 1.3
- $M(^{56}Ni)$ = 0.6 Msun





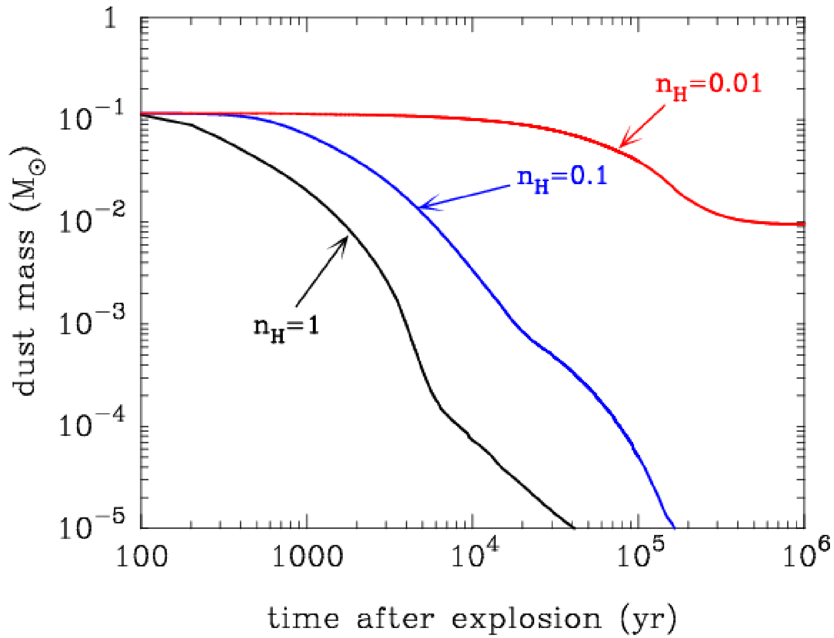
4-2. Dust formation and evolution in SNe Ia

average radius



Nozawa+11, submitted

dust destruction in SNRs



- condensation time :
  100-300 days
- average radius of dust :
  a_{ave} <~ 0.01 μm
- total dust mass :
  M_{dust} = 0.1-0.2 M_{sun}

newly formed grains are completely destroyed for ISM density of n_H > 0.1 cm^{-3}

➔ SNe Ia are unlikely to be major sources of dust

5. Summary of this talk

- **Size of newly formed dust depends on types of SNe**
  - **H-retaining SNe (Type II-P) : a_{ave} > 0.01 μm**
  - **H-stripped SNe (Type IIb/Ib/Ic and Ia) : a_{ave} < 0.01 μm**

    ➔ dust is almost completely destroyed in the SNRs
    ➔ H-stripped SNe may be poor producers of dust

- **Our model treating dust formation and evolution self-consistently can reproduce IR emission from Cas A**

- **Mass of dust in SNe must be dominated by cool dust**
  - **FIR and submm observations of SNe are essential**
  - **SPICA will make great advances on understanding of dust formation process in SNe**